Vol. VI. JANUARY, 1890. No. 9.

American Meteorological Journal.

A Monthly Review of Meteorology and Medical Climatology.

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ANN ARBOR, MICH., U. S. A.:
METEOROLOGICAL JOURNAL COMPANY.
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THE AMERICAN

METEOROLOGICAL JOURNAL.

VOL. VI. ANN ARBOR, JANUARY, 1890. No. 9.

EDITORIAL NOTE.

THE PRIZE TORNADO ESSAYS. — The first prize has been awarded to Lieut. John P. Finley, U. S. A. Signal Service; and the second prize to Mr. A. McAdie, Clark University, Worchester, Mass. There were two essays judged worthy of mention between the authors of which the third prize is to be equally divided. These are Professor H. A. Hazen of the Signal Service, Washington, and Mr. John M. Bennett of Viroqua, Wis. The essays will be published in the JOURNAL in due time.

The editors and publishers of the JOURNAL desire to return their thanks to the many individuals, journals, and newspapers which aided in informing the public that these prizes were offered, and especially to the judges, Professor Davis, Professor Ferrel, and Superintendent Mendenhall of the Coast Survey, who were willing to gratuitously spend their time in reading them and to assume the responsibility of deciding on their merits.

There was a delay in passing on the merits of the essays which was unavoidable on our part and on that of the judges, and which our readers may be interested in knowing. The essays were to go to a hotel in Boston to find one of the judges there. They were delivered at the wrong hotel, were receipted for by the clerk, and lay unnoticed for many weeks. Had it not been for a great deal trouble on the part of Professor Davis they might have never been found again. They were, however, unearthed, and sent again on their travels.

ORIGINAL ARTICLES.

THE MATHEMATICAL ELEMENTS IN THE ESTIMATION OF THE SIGNAL SERVICE REPORTS.

By Walter S. Nichols.

Attempts to measure the value or accuracy of the daily weather reports issued by the Signal Service, are liable to involve a confusion of ideas. Confining the attention to a single feature, that of rain, the proposition may be stated thus: the previous knowledge whether rain will occur within a specified time, has a certain value to the community. The government undertakes to furnish information on that point. Now, several distinct questions may be asked, each having a different answer. We may inquire (1), what is the value of such information to the community?; or (2), how nearly correct is the information thus furnished?; or (3), what degree of skill is shown in obtaining it? The first question is obviously a function of the second, and that in turn is a function of the third. But the practical question is the first. The proper test of the service is its value to the community, and this involves the quantity and quality, as well as the accuracy, of the information.

If the people had no other means of framing a judgment than from the weather bulletin, it would be a case of two events one of which must occur and each equally likely. Any prediction having more than fifty per cent. in its favor would be a gain. If the government assumed only to notify of rain when it might be able to do so, if it were understood that silence on that point meant nothing, then the number of predictions of rain that were verified would be the basis of judgment. But the value of the service would be reduced by its imperfection. But if, as is understood, it undertakes to warn whenever rain is anticipated, then the absence of warning is equivalent to a prediction against the event, and the comparison should be between the total number of occurrences and the predictions. In the one case the occurrence of rain on a day not predicted would

be anticipated as an event likely to occur. But in the other, and in point of fact, the community are led not to expect it unless predicted.

Hence the case may be stated thus: of m predictions relative to rain or its absence, n have been verified; and on the hypothesis above, the difference between half of n and m would represent the gain or loss from the attempted prediction. The actual conditions which exist, however, essentially modify the theory. In the first place it is well known that the chances of rain or its absence are not equal. In the next place familiar weather signs furnish partial information to the community in advance. The value of the information depends on the time in advance that it is given. The increased confidence engendered by a prediction may result in special injury in case of failure. The thing predicted is not a precise event but a variable condition having its own peculiar curve of precision. There may be much or little, long or short rain. Lastly the fulfillment may be partial. There may be rain over the entire territory or over only a small portion. Each of these elements modifies in its own way the value of the forecast.

Taking them in the order named, rain is only an occasional condition. This fact does not necessarily reduce the importance of the prediction. Prior knowledge of an occasional event may be of more value than if it were more frequent. But, ordinarily, the importance of a prediction depends on the degree of uncertainty which is greatest when the chances are equal.

Let A and B be alternate events of which A happens m times, and B, n times. A is predicted p times of which p' are correct. B is predicted q times of which q' are correct. Then we have the following relations.

$$p + q = m + n.$$

The ratio of m to n may furnish some indication of the relative skill required for each class of predictions. The degree of accuracy is expressed by

$$\frac{p' + q'}{p + q}.$$

The accuracy as to each class is expressed by

$$\frac{p'}{p} \text{ and } \frac{q'}{q}$$

if the number of predictions only be considered, and by

$$\frac{p'}{m} \text{ and } \frac{q'}{n}$$

if the number of happenings be considered. But if the comparison be instituted between the correct predictions and the failures both from false predictions and from failures to predict, as it properly should, then the ratios are

$$\frac{p'}{(m-p')+(p-p')} \text{ and } \frac{q'}{(m-q')+(q-q')}$$

Now if previous anticipation of the happening of A brought a dollars, and of B brought b dollars, while the happening of each without such knowledge involved the loss of a' and b' respectively, then we have the elementary problem of the weather report, and the following relations would express the profit or loss resulting from dependence on the predictions and consequently their practical value.

$$p'a + q'b - a'(m - p') - b'(n - q') = P'$$

Whether this result would be a gain or loss to the community depends on what might have been anticipated aside from the predictions. This leads to a consideration of the second point named, the degree of popular information concerning the weather derived from experience, weather signs, etc. If p'' and q'' represent the number of correct anticipations that would be made by an average number of the community, the profit or loss resulting from dependence on such personal judgment would be

$$p''a + q''b - a'(m - p'') - b'(n - q'') = P''$$

With p' and $q' > p''$ and q'', there would always be a gain. But with $p' > p''$ and $q' < q''$ or the reverse, the gain or loss would depend on the relative values of a and b. In other words the relative importance of the thing predicted is an important factor in determining whether a series of predictions have been of service to the community.

Now as to the length of the forecast, a fair judgment from

familiar weather signs can frequently be framed regarding rain, temperature and wind from six to twelve hours in advance, and sometimes longer. A government forecast however accurate, which reaches the average citizen only within this brief time in advance, is apt to have little more than a confirmatory value. Even were it otherwise the time is likely to be too short to make the information available. On the other hand the reliability of local weather signs diminishes in a much greater ratio with the length of the prediction than does the reliability of those meteorological conditions noted by the Signal Service. Hence the value of that service to the community is enhanced by longer predictions even if less accurate, so long as their defect from this cause does not counterbalance the added value of the information. Referring to the formulas above, a and b increase in a geometrical ratio with the length of the forecast, while p' and q'' diminish much more rapidly than p' and q' within that period during which it is possible to cast the horoscope, and government predictions can be profitably made to such time in advance as shall make $\frac{p'}{p''}$ a maximum.

New York, the commercial metropolis, should present a case most favorable to the service. The ordinary bulletin, which now reaches the average business man there through the press at 8 o'clock in the morning, tells him only the forecast for the twelve hours ensuing, when he is already able to judge for himself and his plans for the day are laid. To an intelligent observer in that city a knowledge of the meteorological conditions in the west and south from which he can frame his own judgment of the morrow may be of more practical value than such a limited forecast.

Another important element, involving the accuracy of the prediction, is the partial character of the fulfillment. The value is usually a function of the quantity and duration of the thing predicted. When these do not reach a certain amount the value may be negative. A prediction of rain which is verified only by a trifling fall for a brief period is an example of such nega-

tive value, and suggests the rule that the classification should be carried far enough in all cases to give a positive value to the term employed. For a like reason it should be carried far enough in the other direction to avoid unnecessary vagueness. A prediction of heavy rainfall in connection with the Connemaugh flood or of severe gales in connection with the recent great storm on the Atlantic coast, would have been worth vastly more than a mere prediction of rain or high winds. In the one case the terms suggest the true character of the event, in the other they do not.

The same principles apply to partial fulfillments within territorial districts. Negative values arise whenever the importance of the prediction, in those parts where it is fulfilled, is exceeded by the injury resulting from the partial failure, and predictions should be localized even at the sacrifice of accuracy until such values become a maximum. Just here an important principle comes in play. The greater the value resulting from fulfillment in proportion to the injury resulting from failure, the smaller is the degree of probability that will justify a prediction and the wider may be the territorial range embraced. A probability which would justify a warning of tornadoes or destructive gales, might not warrant an ordinary weather prediction. It is not simply the likelihood of the event but its relative importance, that determines the wisdom of the warning. Referring to the formula above, the larger is a in proportion to b, the smaller need p' be in proportion to p to make a warning of A profitable to the community.

As a matter of fact, the more general or vague the term employed the less can be claimed for the real accuracy of the fulfillment, which becomes more imperfect the wider the departure from the average. If a represent the ordinary amount of rain to be expected from a given prediction, b the territory embraced, and Φy the variation from such amount at each point dy, then the practical accuracy of such forecasts made in general terms for a wide territory, may be expressed by

$$f(a\ b - \int_{y=b}^{y=o} \phi y\ dy).$$

The reduction of b tends directly to reduce the relative importance of the integral, and thus increase the entire value of the function, while it also tends to decrease the latter through the lessening of the probability involved. The accuracy is greatest when the function is a maximum, in other words when the prediction has been as strictly localized and defined as the diminishing probability will permit.

Finally, the problematic character of the language employed such as rain will fall, or is probable, or is possible, is in a crude way a measure of the degree of probability, and is governed by similar principles. It defines more closely the character of the prediction and tends to render positive, values which might otherwise be negative. In so far as it can be successfully employed, it broadens the scope and usefulness of the Service. Conditions that would not justify a positive prediction, might with advantage to the public be expressed as indicating a possibility. A knowledge of the degree of certainty with which an event may be expected, increases the value of the information. Positive predictions of rain, of which only fifty per cent. were fulfilled, might be of little value, or even an actual loss, while predictions of its possibility might be a gain. In the formulas above, the values of a and b are reduced as the knowledge becomes more problematic, but the values of p' and q' increase in a much greater ratio as the degree of certainty is more definitely expressed.

The inferences from this discussion are, that weather predictions are not to be judged simply from their technical accuracy, but rather from their practical value to the community, and that within certain limits such accuracy may profitably be sacrificed for the increased advantage of longer, more localized and more definite predictions. Where the event is unimportant the probability should be correspondingly strong to justify predictions which may tend to discredit the reliability of the reports. But the greater the importance the smaller need be the probability involved, while to avoid the sacrifice of accuracy and confidence the problematic character of such predictions should, as far as possible, be indicated. Any fair com-

parison between the forecasts of the government and those of independent local observers involves all these elements, and is exceedingly difficult to institute. The local accuracy of the one is offset by the broader field covered by the other. But it would seem to the writer that the local officers might be trained with advantage to supplement the present reports with forecasts for their several communities on the lines suggested.

NOTES ON VARIOUS SUBJECTS.

By Professor Richard Owen.

I. *Indian Summer.* As we have recently had, in southern Indiana, a considerable succession of days, presenting the phenomena to which the name of Indian Summer has been given, a record of some of the atmospheric conditions during that period, and suggestions regarding their influence in bringing about this peculiar climatic condition, may perhaps be acceptable in a meteorological journal.

Although we have the high authority of Lieut. Maury for the statement that this phenomenon sometimes occurs in the New England States, and even extends as far as Labrador, yet in its most persistent and characteristic form, namely, that of haziness, rather than fog, and disappearance whenever the sun comes out with its meridian force, the Indian Summer seems more peculiarly a continental climatic condition not often found on seaboards, which partake rather of the so-called insular climate.

Its occasional appearance on the Atlantic seaboard may be due to an extension of that fogginess so prevalent near the banks of Newfoundland, consequent upon the warm gulf stream stream meeting the cold arctic stream.

In the valley of the Mississippi, great differentiation of temperature between the night and that of the preceding or succeeding day, with a moderate amount of moisture in the atmosphere would seem the necessary conditions, as shown by observations, extending through more than half a century, and

generally presenting meteorological statistics similar to those given below, as recorded during portions of the last few weeks.

It may be proper to remark that New Harmony, in which these observations (as well as those given subsequently) were made, is in the central trough of the Mississippi valley about 400 ft. above ocean level, in a medium latitude (about 38° 10′ N.), soil a sandy loam; also to state that the instruments used were Green's standard thermometers of register and other forms. No rain had fallen for over three weeks previous to these observations.

October 19th, 1889, maximum cold, say 3 A. M., 47° F.; at 10:30 A. M., 71° in shade; 81° in sun. No dew; morning quite hazy, dissipated by 10 A. M.

October 20th, maximum cold 51.5°; at 10:30 A. M., 63° in shade; wet bulb 3° lower; wind from northwest. No dew; sun obscured all day; haziness persisted.

October 21st, hazy; maximum cold 38°; at 11 A. M. 56° in shade; 63° in sun; wet bulb 50°.

October 24th, thunderstorm at 3 A. M.; thermometer in shade at 3 P. M., 55°; wet bulb 53°.

October 29th, hazy; maximum cold 34°; maximum heat in shade 56°; in the sun 74°; wind at northwest.

November 2d, two minutes before 2 A. M., shock of earthquake, lasting 6″–8″; direction north and south.

November 3d, at 3:15 P. M., thermometer in shade 56°; in sun 76°; wind from northwest; hazy.

November 4th, hazy; maximum cold probably about 3 A. M., 53.5°; at 8.30 A. M., 46° in shade; 65° in the sun; at 3 P. M., 56° in shade; haziness chiefly dissipated by 9 A. M. Difference between wet and dry bulb 9°.

November 5th, maximum cold 36°; at 11:30. 44° in shade; slightly hazy.

November 6th, hazy, dew; wind from southeast; sun obscured; maximum cold 24°; at 8:30, 41° in shade; wet bulb 7° lower.

November 7th, maximum cold 33.5°; at 8:30 A. M., 43°; at 10 A. M., rain which continued all day.

November 8th, still raining; difference between dry and wet bulb 1.5°, viz., at 9 A. M., dry 50°, wet 48.5°.

The normal type of weather, for this region, is for eight or ten days, wind from northwest, weather cool or cold and dry; then wind gradually shifts to southwest and the weather is mild and rainy, perhaps for eight or ten days; then wind again changes to the north and brings cold and dry weather. Of course there are occasional anomalous varieties, of more protracted drought, or of prolonged moisture; the wind is more rarely from an eastern direction.

After these observations, showing a difference, sometimes in twelve hours, of 20° in the shade and 40° between maximum cold, and hottest sun temperature, it may be of interest to add some records, made during August and September, 1887.

II. *Underground Temperatures at 6 and 12 inches; a few at 2 and 4 feet below the surface.* August 27th, 1886, at 2 P. M., air in shade, 90° F.; in the sun, 120°; on sandy surface in sun, 135°; six inches below garden soil 115°; at twelve inches below 95°; the holes were freshly made with a post digger, and the thermometer was lowered immediately.

August 28th, at 2:45 P. M., air 90°; sun 105°; on surface of sand 120°; 6 inches below 98°; 12 inches 90°.

August 29th, at 8:15, air 87; sun 94; surface of soil 101°; 6 inches below 87°; 12 inches 86°.

August 30th, 8 A. M., in shade 85°; in sun 89.5°; on surface, garden 93°; 6 inches below 85°; 12 inches below in garden or yard 85°; 12 inches below in woodshed 77°; soil being shaded from sun.

September 2d, after rain; at 8:30 A. M., air 77°; sun 82°; 12 inches below in woods 75°; 12 inches below in the yard 76°; at close of experiment air 78°, sun 85°, surface 90°.

September 3d, 9 A. M., clear, air 78° to 79°; sun 85° to 86°; in woodshed, at 1 foot, 76°; in garden in shade, at 1 foot, 75°; at 4 P. M., at 1 foot in woodshed 77°; at 1 foot in garden 80°.

September 5th, 9 A. M., air 86°; sun, 3 feet above ground, 92°;

on surface of sandy soil in garden 95°; 1 foot below in the woods 77°; 1 foot below in the garden 77°.

September 6th, at 2 P. M., air 92°; sun 97°; 2 feet under ground 79°; at 4 feet 75°.

September 7th, at 3 P. M., air 90°; 1 foot below soil 78; at 2 feet 77°; at 4 feet 74°.

September 8th, at 8 A. M., air 82°; 1 foot below soil 77°; at 2 feet 77°; at 4 feet 76°.

September 9th, at 8:15 A. M., 79°; 1 foot below soil 77°; at 2 feet 77°; at 4 feet 75°.

These observations were continued for a considerable time longer, with similar results; but the above may suffice to show the average decrease in temperature as we descend, in our latitude, for perhaps 60 or 70 feet, dependent partly on the nature of the soil;* after which the temperature of course increases.

The temperature in the New Harmony wells, which have a depth of from 26 to 30 feet, varies slightly with the season; in some the thermometer indicates 58° F. in summer, and 56° F. in winter; in another it falls as low as 55° F.

The water, in these wells, rises and falls with the rise and fall of the Wabash, although the river is from one-third to one-half mile distant, the soil however, as remarked above, is a sandy loam.

The temperature of the Wyandot Cave, found during the eight miles which our party traversed in making the geological survey in 1860, varied somewhat, being in some places 54°, in others 57°, dependent on the character of the superincumbent rock and soil.

Humboldt states that at Brussels, the thermometer record, made 24 feet below the surface, did not show the maximum cold nor the maximum heat, until about six months *after* these maxima occurred at the surface.

III. *The Compass-Plant.* The *Silphium laciniatum* (Rosin-Weed or Compass-Plant) merits some discussion in a meteor-

*Humboldt in Vol. IV of his Cosmos, (p. 39 of the English edition) gives the "*invariable* stratum in the lat. of Paris (48° 50') in the Caves de l'Observatoire," at 86 Paris feet or 92 English feet; and the temperature 53.3° F. or 11.834 Cent.

logical journal in consequence of its peculiar phenomena, apparently magnetic.

Prof. Asa Gray, in his "Manual," p. 120, says: "Lower leaves 12'—30' long . . . . said to present their faces uniformly north and south." This statement is liable to be misunderstood. The lower leaves stand vertically, and present one face to the east, the other to the west; consequently the *plane* of the leaf has a north and south direction. Instead of having, like most leaves an upper side, "with an epidermis for tempering the action of direct sunshine," as described in Gray's "Lessons," p. 156, and "an under surface with about 100,000 stomates or breathing-pores," the Compass-Plant shows *each* surface of the leaf destitute of epidermis, rough and resinous.

It may be that the large amount of resin which the leaves of this plant contain, judging from the dense volume of black smoke resulting from their ignition, which gives rise to the popular name of the plant, may protect the leaves, in the habitat of the plant, the prairies of temperate latitude in the central United States (Minnesota, Iowa, Wisconsin, Illinois, Indiana, etc.) from the wilting effects of a hot sun; in the same way that the resinous coniferæ of northern climes afford sufficient protection for their reproductive organs in their resinous needle-leaves, and equally resinous naked—seeded cones.

It occurred to me that the large amount of resin in the leaves of the plant might have considerable effect in causing them to grow in planes running north and south, although as stated in Ganot's "Physics," p. 750, essence of turpentine sets equatorially, or diamagnetically.

Not having electro-magnetic apparatus sufficiently powerful to make the necessary tests, I ventured, in consequence of my fifteen years' connection with the Indiana University, to tax the kindness of Prof. J. P. Naylor, M. S., of the department of physics, in that University. He courteously agreed to have some of his advanced students make the desired experiments, which resulted as follows.

1. A filament of resin, suspended, free from the effects of torsion, set paramagnetically.

2. After several unsuccessful attempts, on my part, to obtain fresh leaves of the plant, a friend finally sent me two from Minnesota, which I at once forwarded to Prof. Naylor. He found them, when suspended by the petiole, to set so decidedly axially, or paramagnetically, that they did so, even between the poles of a common U magnet.

The professor then tested other leaves and writes:

"Stem of grass neutral. Stem of maple leaf slightly, but distinctly, paramagnetic. Mid-rib of beech leaf paramagnetic. Blade of maple leaf neutral. Blade of beech leaf neutral. The blade and mid-rib of the Compass-Plant are, however, both very distinctly paramagnetic, the mid-rib especially so."

It may be worthy of remark, as at least suggestive, that the Compass-Plant occupies prairies almost due south from the magnetic pole in Boothia Felix (when and where the needle was at its greatest westing for middle Europe); and again the resinous phyllodia of Australia are about due north from the south magnetic pole of the same period, as determined by Sir James Ross.

IV.—*Experiment bearing on Molecular Physics.** The experiment, detailed below, can be readily repeated by any one; and seems to throw light on some molecular phenomena in magnetism.

Select sixteen needles of the same size; mark eight of them by running a white thread through the eye, knotting the thread and cutting the ends short. Perform the same on the other eight, with red thread in order to distinguish them from the first eight. Then magnetize the former eight by drawing the north pole of a strong magnet, a few times, from point to eye; and magnetize the latter eight by using south end of magnet, and drawing from eye to point. Now pair them, eye to point,

* As Faraday found oxygen the most highly paramagnetic of all the gases, it may be, in accordance with Ampère's theory, that each molecule of atmospheric oxygen is surrounded by a current of electricity (as he supposed to be the case with steel and other bodies setting axially); hence the bearing of this experiment on electrical, atmospheric phenomena, inasmuch as a flash of lightning, which often renders steel magnetic, might impart polarity to the otherwise neutral oxygen molecules.

each needle with white thread being mated with one in red.

Cut a piece of pasteboard, an inch wide, and seven to eight inches long, sufficient to take four lengths of needles. If time permits, the pasteboard should be varnished to prevent its becoming water-soaked. On this pasteboard, place the sixteen needles in fours, ends to ends; namely, two couples at each end, and two couples in the two intermediate spaces. Then carefully lower the pasteboard into a basin of water, so as to float on the surface, and apply your magnet first at one end, then at the other. The float will be found *neutral*, inasmuch as either end of the magnet will attract each end of the floating needle-board.

Now raise the pasteboard and needles carefully out of the water, on to a table, and place over them a strip of writing paper to prevent the magnet from sticking to them. From the centre of the pasteboard, draw the north pole of your magnet, several times over the paper to one end of the pasteboard; then with the south pole of the magnet, the same number of times from centre to opposite end.

When the pasteboard is again floated, the sixteen needles will be found a perfect magnet, with north and south *polarity*; the eight magnetized by the north end of the magnet being attracted by the south and repelled by the north; while the eight magnetized by the south end will be attracted by the north and repelled by the south.

The *first* float was evidently in the condition of unmagnetized steel, when each needle, representing a molecule, is rendered *neutral* by its mate; but in the *second* float, the combined needles have been brought into the condition of magnetized steel, and hence exhibit *polarity*.

The experiment may be varied by using a greater number of needles, and placing them on a piece of thin pine wood or cork.

NEW HARMONY, INDIANA, November, 1889.

TORNADOES IN MAINE.

STATE TORNADO CHARTS.—MAINE.

By LIEUT. JNO. P. FINLEY, Signal Service, U. S. A.

TABLE I.—*Tornadoes in Maine.*

Period of observation, 29 years, 1860–1888.

Total number of storms,—7.

Year of greatest frequency, 1885,—2 storms.

Average yearly frequency,—0.5 storms.

Year in past ten (10) years, no report of storms,—1879, 1880, 1882, 1883, 1886, 1887 and 1888.

Month of greatest frequency, July,—4 storms.

Days of greatest frequency, July 9th and 16th, 2 storms each.

Hour of greatest frequency, 4 to 5 P. M.

Months without storms,—January, February, March, April, June, September, November and December.

Prevailing direction of storm movement, NE.

Region of maximum storm frequency, southwestern portion.

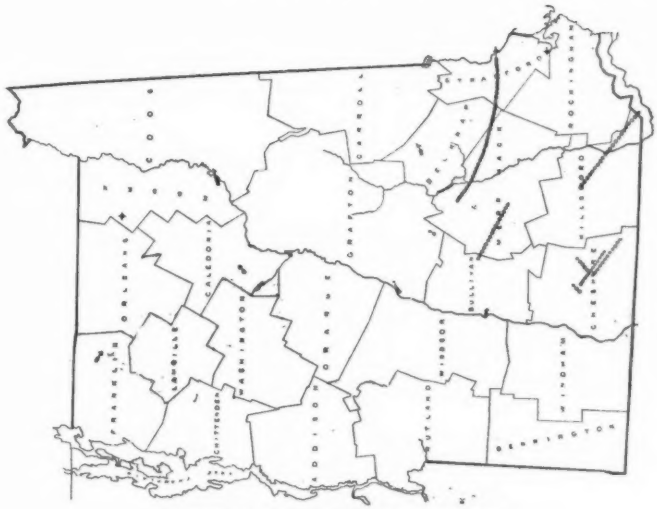
TABLE II.—*A Chronological Table showing the location, date and time of occurrence and general character of formation and movement of Tornadoes in the State of Maine, for a period of 29 years, from 1860 to 1888.*

County.	Month and Day.	Year.	Time.	Direction.	Form of Cloud.	Width of Path in Feet.
Cumberland	July 9.	1860	5 p. m.	E 30° N.	Funnel.	10 to 330.
Hancock	July 16.	1874	.....	.....	.....	.....
Washington	May 14.	1877	.....	.....	.....	.....
York	July 16.	1881	4:30 p. m.	NE.	Funnel.	600 to 900.
Cumberland	October 18.	1884	10:20 a. m.	NE	"	.....
Kennebec	July 9	1885	4:20 p. m.	NE.	"	50 to 130.
Oxford	August 13.	1885	4:30 p. m.	NE.	"	25 to 30.

TABLE III.—*Relative frequency of Tornadoes by months and days, for Maine.*

The index figures to the right and above the dates show how many times tornadoes occurred on that day of the month.

Month.	Day of Month.	No. of Days.	Total No. of Tornadoes per month.
May	14^{1}	1	1
July	$(9)^{2}$ and $(16)^{2}$	2	4
August	13^{1}	1	1
October	18^{1}	1	1
Total		5	7



TORNADOES IN NEW HAMPSHIRE AND VERMONT.

STATE TORNADO CHARTS.—NEW HAMPSHIRE AND VERMONT.

By LIEUT. JNO. P. FINLEY, SIGNAL SERVICE, U. S. A.

TABLE I.—*Tornadoes in New Hampshire.*

Period of observation, 82 years,—1807–1888.
Total number of storms,—10.
Year of greatest frequency, 1880,—3 storms.
Average yearly frequency,—1.3 storms.
Years in past ten (10) years, no report of storms, 1879, 1881, 1882, 1883, 1884, 1885, 1886 and 1887.
Month of greatest frequency, July—4 storms.
Days of greatest frequency, June 6th and July 25th,—2 storms each.
Hour of greatest frequency, 4 to 5 P. M.
Months without storms,—Jan., Feb., March, April, Nov. and Dec.
Prevailing direction of storm movement, NE.
Region of maximum storm frequency, southwestern portion.

TABLE I.—*Tornadoes in Vermont.*

Period of observation, 60 years,—1829–1888.
Total number of storms,—6.
Year of greatest frequency, 1888,—2 storms.
Average yearly frequency,—0.3 storm.
Years in past ten (10) years, no report of storms, '81, '82, '83, '84, '85, '87.
Month of greatest frequency, July,—3 storms.
Day of greatest frequency,—no day having more than one storm.
Hour of greatest frequency, 4 to 5 P. M.
Months without storms, Jan., Feb., March, April, Sept., Oct., Nov., Dec.
Prevailing direction of storm movement, NE.
Region of maximum storm frequency, northern portion.

TABLE II.—*A Chronological Table, showing the location, date and time of occurrence, and general character of formation and movement of Tornadoes in the State of New Hampshire for a period of 82 years, from 1807 to 1888.*

County.	Month and Day.	Year.	Time.	Direction.	Form of Cloud.	Width of Path in Feet.
Cheshire	July 25.	1807	About noon.	NE.	.....	412 to 495.
Cheshire	"	1807	Noon.	NE.	.....	.....
Sullivan and Merrimack	September 9.	1821	5:30 p. m.	SE.	Funnel.	330 to 1,000.
Rockingham	October 1.	1847	.....	NE.	.....	.....
Cheshire	August 3.	1854	.....	SE.	.....	1,320.
Cheshire	July 1.	1877	.....	SE.	.....	.....
Grafton	May 20.	1880	Afternoon.	NE.	Funnel.	.....
Grafton	July 16.	1880	Afternoon.	NE.	.....	400 to 600.
Merrimack	June 6.	1880	4 p. m.	Easterly.	Funnel.	1,320.
Belknap	"	1888	3:10 p. m.	NE	"	300.

TABLE III.—*Relative frequency of Tornadoes by months and days, for New Hampshire.*

The index figures to the right and above the dates show how many times tornadoes occurred on that day of the month.

Month.	Day of Month.	No. of Days.	Total No. of Tornadoes per month.
May	20	1	1
June	(6)[2]	1	2
July	1, 16 and (25)[2]	3	4
August	3	1	1
September	9	1	1
October	1	1	1
Total	.....	8	10

TABLE II.—*A Chronological Table, showing the location, date and time of occurrence, and general character of formation and movement of Tornadoes in the State of Vermont for a period of 60 years, from 1829 to 1888.*

County.	Month and Day.	Year.	Time.	Direction.	Form of Cloud.	Width of Path in Feet.
Caledonia	August 9.	1829	5 p. m.	NE.	Funnel	Narrow.
Orange	July 14.	1879	5:45 p. m.	NE.	Inverted cone.	3,000.
Essex	May 10.	1880	.....	.....	Funnel.	900.
Windsor	July 30.	1886	Afternoon.	E.	"	500
Essex	June 6.	1888	4 p m.	NE.	"	2,640.
Franklin	July 20.	1888	5 p. m.	SE.	"	1,320.

TABLE III.— *Relative frequency of Tornadoes by months and days, for Vermont.*

Month.	Day of Month.	No. of Days.	Total No. of Tornadoes per month.
May	10	1	1
June	6	1	1
July	14, 20 and 30	3	3
August	9	1	1
Total		6	6

THEORY OF STORMS, BASED ON REDFIELD'S LAWS.

By M. Faye, Membre de l'Institut, etc.

(continued from december number.)

4. *Region of Calm in the Center of a Storm.*—There is scarcely a more extraordinary phenomenon in Nature, than the calm which prevails in the center of storms, and probably in all gyratory movements,—in the place where the spirals on nearing the axis must take a velocity almost infinite. The transition from the most violent wind to an almost absolute calm is sudden. The inexperienced navigator thinks that the storm is over, and the sailors begin to repair its ravages; but the tempest which passes over them is still in progress; the region of calm advances with it, and when the opposite boundary arrives the wind blows with renewed fury in a direction contrary to the first.

Observation shows that the region of central calm, so clearly circumscribed, exists not only below, but through the whole height of the whirl. It is a hollow around which the descending spirals turn furiously. It might be called a long, bell-shaped tube opening upwards, a sort of hyperboloid of revolution piercing the thick clouds, through which a portion of the blue sky appears near the zenith.

This phenomenon, so striking, so imposing, does not appear upon the synoptic charts. Although known for a long time, meteorologists do not appear to have given it serious attention. They seem to find in it a terrible obstacle to their theories: the attentive observation of this phenomenon, and the experiments by means of which we have reproduced it in miniature, will help us to complete ours. We have numerous examples of vessels which have traversed the region of calm in a tempest, upon every sea of the globe. We will limit ourselves to the citation of one, and we will add to it one case where this phenomenon was registered with all its details in a stationary observatory.

November 20, 1854, the *Julius Cæsar*, Captain Gachet, returning from India to the Reunion, was in 6° south latitude,

and 83° east longitude, when the weather became threatening, the barometer fell, and the wind from the SE blew with the greatest violence. The 21st at 2 o'clock P. M., it blew a hurricane. The netting was carried away by a monstrous wave, rain fell in torrents and the sinister lightning flashes furrowed the sky at every instant, on all sides. At 9 o'clock in the evening the wind which had blown from the ESE and E ceases suddenly and an hour's calm succeeds the terrible blasts of wind which they had just passed through. During this time the sky is magnificent in the zenith; the stars shine out in all their splendor, obscured now and then by a light mist which passes rapidly from the northwest; the reddish lightning flashes succeed each other without interruption in the northwest. At 10 o'clock the hurricane is again unchained from the west and northwest with undiminished force. The ship escapes only after losing its sails and boats.

We will see why this phenomenon is more rarely observed in high latitudes; it never fails up to the 30th, or even the 40th degree. It is an essential trait of the constitution of all cyclones not yet deformed.

Now follows the second observation: meteorological observatories, furnished with registering instruments, have been so multiplied in number during the last years,—even near the tropics, that a cyclone might pass centrally over one of them and itself inscribe upon their daily record sheets, decisive elements which a mariner, fighting with the storm, would have neither the time nor the idea of noting. This is what happened in the typhoon of October 20, 1882, which passed centrally over Manilla, and almost centrally over the Spanish observatory of the capital. Everything was recorded, not only the barometer and the direction of the wind, as would occur on board ship, but the force of the wind, the variations of the thermometer and those of the hygrometer. Here I will let Dr. Sprung speak; he is the author of a learned treatise on meteorology, published at Hamburg four years ago.

"It cannot be sustained absolutely, that there does not exist a descending movement in the interior of cyclones. A phe-

nomenon which seems to speak for it, is that which has been called the *eye of the storm* in tropical cyclones. It consists in that,—at the moment of the lowest drop in the barometer,—the sky clears, entirely or partially. There is an opening in the lower clouds through which appears the blue sky, or at least the veil of cirrus of the highest regions. This is what occurred for example at the time of the hurricane of October 20, 1882—of which the different phases were recorded so completely at Manilla, by the instruments at the observatory. At the moment when the center passed over Manilla, the barometric curve recorded in $3\frac{1}{2}$ hours a depression of 23 mm. The velocity of the wind, which had increased from 10 meters to 54 meters per second, dropped suddenly. Then, after a calm of 15 minutes, the two elements, not less suddenly, resumed their preceding values."

"It was otherwise with the temperature and the humidity. The former which held constantly at 26° from the beginning of the hurricane, rose suddenly to 31° at the beginning of the calm, and dropped no less suddenly to 24° at the end of the calm. Entirely in correspondence with these variations, the relative humidity lowered from 98 per cent. to 53 per cent.—dryness rarely observed in these regions. *These phenomena, so characteristic, can evidently be explained only in admitting the existence of a descending current of air in the center of the whirl.*"

"The theory of cyclones, it must be admitted, does not accommodate itself well to the existence of such a descending movement in their interior. But this descent is probably limited to the lowest strata of the atmosphere. Besides, it cannot well be considered as making an essential part of the system of a storm, for the *eye of the hurricane* seems to be an exception rather than the rule. It is perhaps only a transitory phase in the normal development of a hurricane."

The reflections of Dr. Sprung show how a preconceived idea, such as the power of aspiration of cyclones and tornadoes, tends to show facts in a false light. He admits an opening in the lower clouds, but he will not believe that it extends to the

cirrus. He is inclined to think that the central calm is a pure accident. On the contrary, it is a constant fact. In all cyclones which vessels have traversed near the center, this region of calm, so striking to the sailors themselves, has been verified. It is not an exception in the normal development of a hurricane. It is met with in all latitudes between the point of departure at 6° from the equator, and 42° of latitude, and even beyond that. It is necessary, then, to hold to the plain conclusion of Dr. Sprung himself, and admit that a descending current of air exists in the interior of whirls. The difficulty which stops the German meteorologist disappears on admitting that the entire whirl is descending.

5. *Study of the Central Calm.*—It is a fact that the air of this region of calm, so clearly defined, does not participate in the violent gyrations by which it is enclosed. But the calm is not absolute, for the air contained in this bell-shaped tube follows the storm in its progress; and it is also a fact that the air descends from the region situated above the cirrus—above the generating current of cyclones. It is descending, and the decisive reason for it has been seen; it comes from the region above the cirrus, for should air from the cirrus stratum be drawn downward the cirri would produce clouds which would cover the sky. Finally, the reason of the passage of this upper air through a thick stratum of cirrus is to be found in the gyration itself; that is, to the centrifugal force which develops rapidly in the spirals, in proportion as they approach the funnel-axis, and begin to turn more rapidly. There is doubtless in every section perpendicular to the axis an area where the gyrations cannot penetrate, and this is limited by the circle upon the circumference of which the centrifugal force is in equilibrium with the tendency towards the axis. It were much to be desired that all this might be verified experimentally, not upon whirls in water-courses, which are not entirely suitable, but by the aid of some artifice. We will try it by the aid of a beautiful experiment, which M. Hirn studied from another point of view in his remarkable pamphlet, entitled "Studies Upon a Special Class of Whirls."

Given a cylindrical vase filled with water, which has a height h, and of which the bottom is pierced by a circular orifice--rather small, as compared with the section of the vase. If this orifice is opened when the water is quite still, the flow takes place with a rapidity which analysis easily determines: it is that of a body which falls freely from the height h; and will have for expression $v\sqrt{2gh}$. But this analysis is based upon the hypothesis of the parallelism of the sections. It is admitted that the upper surface of water remains plane and horizontal, and that the horizontal sections of which it is supposed that this mass is composed, descend parallel to themselves without deformation.

In fact the experiment shows something like this: On throwing fine opaque dust into the liquid it descends in almost equal quantities from one section to the other. Nevertheless the phenomenon changes close to the orifice toward which the dust of the last section converges conically. The above formula, then, is only an approximation which suffices when h is so great that what occurs below may be neglected, but it becomes quite inexact when the upper level approaches the bottom and is only a few centimetres from the orifice. I do not know that any analyst has tried to solve this extreme case.

Let us now suppose that the water being at the height h the orifice is closed and that a movement of rotation about the axis is communicated to the whole mass of water contained in the vase. It has already been seen that if the rotation becomes constant, the upper surface of the water will become hollowed out in form of a paraboloid of revolution, and that the molecules, at all heights, will circulate around the axis with a linear velocity inversely proportional to their radius of gyration. This established, if you remove, in thought, from the center of any section, a portion of the fluid, the molecules of that section will move towards the vacancy. In nearing the axis their angular velocity will augment; but at the same time the centrifugal force which will increase in the ratio of the square of this velocity, will tend to maintain them at some distance from the axis, and the supposed vacancy will not be entirely filled by the molecules of the section which is under consideration.

This is what happens in the last section if the orifice be opened. A part of this section will disappear immediately by falling outside the vase. The vacuum thus produced, will be filled, only in part, by the molecules of this same section, the rest will be filled by the molecules falling from the section above. The latter will present the same phenomenon as the former. It may be observed then, that, step by step, a hollow canal will be established the whole length of the axis, where molecules of water cannot penetrate so long as the flow continues with sufficient rapidity.

This hollow canal which extends, in widening, from the bottom to the free surface of the water, will not remain empty: the upper air will descend and form in the middle of the liquid a descending current independent of all rotation.

The experiment is easy; I have performed it in public several times, with complete success, in maintaining the water of the vase at its original level by a horizontal jet of water—but oblique to the walls of the vase, in such a manner as to make the rotation more active. As to the inside walls of this funnel-shaped canal, they have a stability so great that if a long rod should be introduced into it, while holding it by the end, the contact of this rod would disturb nothing. In just touching the surface of the water, the rod would take a conical rotation which would be more rapid the farther it penetrated.

This experiment offers a striking representation of the vast column of calm air which is found at the center of all cyclones, and probably (in much smaller dimensions) in the center of all tornadoes. There is nevertheless a difference which merits consideration. To transform the simple movement of rotation in the water of the vase into a cyclonic or whirling movement it has been necessary to offer a free flow to the descending water. If the orifice be opened, the whirl disappears quite promptly; it is closed below like a very long sack; its lower extremity rises, and finishes by attaining the surface. To maintain the phenomenon as we have just described it, it is necessary to produce artificially a rapid gyration; the descending water will escape below, at the bottom of the vase, with the air

which ascends in bubbles around this *trombe*. The water will also ascend along the walls of the vase and thus will form a circulation which will modify the phenomenon. In cyclones, where the whirl is produced by entirely different causes, the second effect will not be produced, for the quantity of air drawn below is insignificant as compared to the mass of the atmosphere; besides the gyrations near the axis have a very different velocity from that in our little vases, because of the enormous extent of the mouth.

Thus, save these differences which are not essential, these two phenomena may be considered analagous and the second may be explained by the first. If this analogy is exact it follows: first, that the air of the calm in the tempest comes, not from the aerial stream where it is formed, but from the air placed above this stream, that is to say, from a region higher than that of the cirrus; second, that this descending air does not participate sensibly in the gyrations of the cyclones, but only in its movements of translation. Now these are the exact deductions which we have drawn from the direct study of this region of calm.

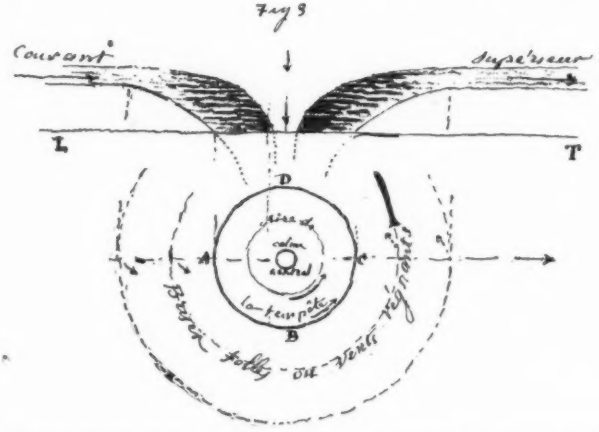
6. *Structure of a Cyclone.*—The height of a cyclone is the depth of the aerial river which carries the cirri where the cyclone originates. Near the equator this altitude is from twelve to fifteen thousand metres. The horizontal diameter at the level of the surface is at least from 1° to 2°, that is, ten or fifteen times greater. Without caring to be exact in these ratios, it is evident that a cyclone is a sort of frustum of a cone, with bell-shaped exterior walls, much inclined to the horizon, with a central canal several miles across, by means of which the upper air, free from cirrus, descends to the surface. I have sought to represent this ensemble in Fig. 3.

The upper part, above the line of the surface *LT*, is a vertical section passing through the axis. The lower part is a horizontal projection upon the surface. It is not a revolving disk as has been said, but a whirl reduced to the part next the mouth. If the surface were situated lower, the whirl would elongate in descending to it; it would take the form represented by the shape

represented by the broken lines upon the vertical section, that is the shape of a gigantic tornado.

Between these parallel planes, that of the mouth and that of the surface, distant from ten to fifteen thousand metres from each other, move about a central calm, as around an axle, the descending spirals of the cyclone. Since the velocity of gyration increases rapidly near the axis, the spirals could not miss forming different systems, centered upon the same axis, of different radii, but descending with the same velocity, and bringing different proportions of cirrus.

The figure below shows that one may be under a cyclone with-



out being reached by it, for the mouth precedes considerably the base of the cyclone,—that is, the circle *ABCD* at the beginning of which the tempest commences for us. The circle which is marked with a strong black line upon the figure is the true limit of the cyclone; it is quite as characteristic as for *trombes* and tornadoes where it is marked at the intersection of their nebulous sheath with the surface, and it is essential to distinguish the domain of the storm and the surrounding region which is exposed indirectly to its influence, but not to its gyrations.

At the passage of the spirals superposed horizontally, the barometric pressure diminishes below. The isobars are cir-

cular and concentric at the region of interior calm. The arrows of the wind are parallel to these isobars solely because they are perpendicular to the radius.

Beyond the horizontal track of the cyclone the atmosphere is in the state in which it was before the arrival of the storm. Only the diminution of pressure due to the upper spirals which made the circle *ABCD* will be felt, and if the atmosphere is calm, the isobars relative to this region will also be circular, but with a very weak gradient. The air will have a feeble tendency towards the cyclone; the arrows of the wind will be no longer parallel to the isobars, but perpendicular to these curves, except the little deviation due to the rotation of the earth. It is certain, at least, that in the region exterior to the cyclone there are only stray breezes; puffs of warm air without relation to the winds will not fail to blow with violence as soon as the storm declares itself. The only way for the observer to know in advance the direction which the latter will take, is to observe that of the little clouds which move with rapidity above his head, because these clouds are carried by the upper spirals parallel to those below.

The observer, placed below a cyclone but outside of the circle ABCD, often experiences, in the midst of the calm which we have just described, an indisposition—or strong oppression—at the approach of the tempest. This effect is due to the cirrus, which begins to descend. A nebulous veil then extends over the sky, reduces the radiation towards space, concentrates the humidity of the lower strata, and elevates notably the temperature until the moment when the observer is reached by the circle ABCD—that is, by the spirals descending from the upper regions.

But if the lower strata of the atmosphere were submitted to a region of prevailing wind like the trade-winds or the monsoons, the cyclonic spirals would be represented as descending in the midst of the strata without changing their motion of translation; the effect produced would be a composition of the two velocities. It is scarcely perceptible in the interior of a cyclone because of the great preponderance of the velocity of

gyration but it is different upon the outskirts of the storm. It is thus that in the southern hemisphere when a ship going from the East Indies to the Cape of Good Hope, encounters a cyclone in the region of the SE trade-winds, they seem to blow tempestuously because to their own velocity is added that of the spirals of the advancing cyclone. Per contra, the rear of the trade-wind is suppressed for a time by the gyration which blows from the NW and there results a calm. It seems that the exit from a cyclone is more rapid than the entrance into it. I noticed an analagous circumstance concerning the cyclone of Aden which caused us the loss of the vessel *Le Renard.* The German maritime observatory believed that it showed a momentary weakening which was quite embarassing; I have shown that this phenomenon was due simply to the fact that at the indicated points the monsoon from the NW began to blow in a direction contrary to that of the gyration, at a little distance from the center.

Upon contact with the earth the air carried downward by the descending spirals, escapes tumultuously in all directions. As it rises under a slight inclination this air rebounds at first in a vertical plane tangent to the spirals, but resistances of all sorts and its small mass prevent it from producing well marked currents. Probably the air, which ceases to form a part of the cyclone without a tendency to rise, serves only,—after whipping the ground or the sea,—to interrupt the regularity of action of the spirals which thereafter seem to blow in blasts rather than continuously. The whistling and howling of the tempest results from this conflict of which it is difficult to form an idea. We will study this more in detail when we come to the tornadoes, and especially the *trombes* in the cloud regions, in the second and third parts of this work.

An action not less powerful is produced upon the sea. The violent impact of the spirals also engenders no current, but drives outwards on all sides from the circumference of the cyclone, enormous waves, which move rapidly, and give rise to the destructive storm floods on low coasts.

These phenomena announce tempests two or three days in

advance. It is especially the spirals parallel to the trajectory on the dangerous side which produce the most marked effects. At the Island of Reunion this premonition has never failed; the progress of a cyclone may be estimated from the points on coast which are attacked.

(TO BE CONTINUED.)

MICHIGAN RAINFALL.

By N. B. Conger, Director of State Weather Service.

I. *Normals for January.*—The distribution of the precipitation, rain and melted snowfall, for the State for the month of January, is unevenly divided. A glance at the chart of the normal precipitation for this month (which will appear in the Journal for February) shows that the northern section receives the largest amount, and this amount shades off to less amounts in the upper peninsula and the south half of the State. The average precipitation for the northern section is 3.06 inches with the average maximum at Mackinaw City of 3.63 inches.

In the south half of the State it will be noticed that there is a path of light precipitation, of less than two inches, running northeast and southwest, in which the average is about one and three-quarters inches.

The values from which this chart was constructed were obtained from records extending from 1876 to 1888, with the exception of the older stations of the Signal Service, which extend back to 1871.

In the upper peninsula the precipitation from 1872 to 1877, with the exception of 1876 at Escanaba, was less than one inch, while the maximum amount of 3.14 inches was not reached until 1886, at Marquette, and 4.80 at Escanaba, the same year.

The maximum amount in the northern section, 8.09 inches, occurred in 1884, at Mackinaw City; in the central section the maximum amount on the east half of the State occurred in 1881, and on the west side, in 1887; in the southern section, a heavy precipitation was recorded at Detroit, of 5.16 inches, in 1874,

and there is not recorded again a large amount in this section until 1880 when the amount was above three inches.

Light precipitation in the southern peninsula, is not general during this month, as amounts of less than one inch, have only been recorded in the following years, at the stations selected: Detroit, 1875, once in 19 years; Port Huron, 1879, once in 15 years; Grand Haven, none; Alpena, 1875 and 1878, twice in 17 years; Thornville, 1879 and 1883, twice in 13 years; Kalamazoo, none in 14 years; Adrian, none in 12 years; Niles, 1879, once in a record extending from 1878–1882. These records go to prove that this State as regards precipitation, is not subject to either excessive precipitation nor to drouths, and that neither of these extremes occur in all sections of the State in the same years but are well distributed, so that if one section is suffering from drouth, other sections are well supplied with moisture.

SLING-PSYCHROMETER: FROSTS.

By Professor H. A. Hazen.

There is a paper on the prediction of frost in the October number of this Journal that is of much importance. It will be recognized by all interested that an approximate pre-knowledge of a severe and killing frost in the spring and fall would be of inestimable value to farmers. I remember that the damage by these frosts, in a single year, was put in the billions in a former Journal. It has been generally recognized that no severe frosts will occur when the dew-point in the early evening is at 30° or above. It is objected in the above article:

1. That we do not know accurately the dew-point at the leaves of the plant. I do not think this a very serious objection, because the dew-point at 5 or 6 feet above the earth will be lower than that of the leaves at 10 feet. The condition of sod, for lowering the temperature by radiation, is very different from leaves freely suspended in the air, and because of this, frost will occur on the sod much more quickly than on leaves.

2. "That the accurate determination of the dew-point requires

an excellence of instruments, an accuracy of observation and a skill in using tables which very few, of those interested practically, are willing to acquire and learn." This might have been said very properly six years ago, but can hardly be said now. Undoubtedly this has been one of the most difficult problems that the modern meteorologist has been called upon to practically elucidate, and yet the results of two independent workers have been compared and found to agree so closely that it may be said, there is very little more work needed to make the psychrometer an instrument of great accuracy. Almost the whole difficulty in solving the problem lay in the lack of a proper ventilation of the psychrometer. Saussure, one hundred years ago, tied a string to the wet bulb and whirled it through the air, and, Bravais, in 1836, did the same thing to a dry bulb, in order to obtain the true air temperature. Espy in 1831 used a sling-psychrometer but the results below 32 were very unreliable. Doyere in 1855 used two thermometers as a sling protected by a copper case and made a few observations which are not very satisfactory. The use of this instrument does not seem to have made any headway till 1883, but since that time the sling-psychrometer has proved all that was needed for the greatest precision.

Any one can join a wet and dry thermometer together, with the bulb of the wet about one inch below the dry, and then by a string whirl them a few times through the air. It is not too much to say that, if the thermometers are accurate, there is no difficulty at all in obtaining the dew-point within one or two degrees, and this is all that the most precise would desire for frost warning. If one has a valuable crop that he wishes to protect, it is probable that this can be done at not very great expense as follows:

Get the dew-point at the level of the leaves or in open ground (I mean open to the sky) at about 6 feet. If this is taken in half a dozen different places it will probably be found that it varies only very slightly. If the dew-point in the evening is at 25° or below and the air is 45° or lower and rapidly falling, with a clear sky and little or no wind, it is very probable that a killing

frost will occur. Let there be placed, on the windward side of the field, several rows of bunches of straw, or heaps of dry weeds or leaves, at right angles to the wind direction, and the rows sufficiently long to practically cover the field with the smudge. There is no danger of freezing or frost, till the air temperature or the temperature of the leaf reaches 30°, and this will not ordinarily be till long toward morning. Let one row of straw be fired as speedily as possible and if the smudge is blown away another, and so on. By watching the air temperature carefully, carrying the sling-psychrometer to different points of the field, there would seem to be no reason why, in a calm or nearly calm, frost may not be prevented. It will be found that in a wind there is much slower diminution of temperature and less danger of frost. Of course it is known to all that frost is much less likely to occur on a knoll or side hill than in a valley, and plants less than two feet in height will be injured much more quickly that those above four feet.

In this connection it may be well to make a single remark regarding the tables. These are now so constructed that a child can handle them without difficulty, and determine the dew-point at a glance, when the wet and dry temperatures are given. Attempt has been made, however, to extend these tables far beyond their accurate value. We have no observations at extreme dryness or cold and it is obvious that if the formula is carried beyond the limit of accurate observation the results must be only approximate. There is another important consideration which relates to the use of one of the recent formulas at extreme dryness. In this formula, from theoretical considerations, it was deemed best to introduce a factor depending on the wet bulb temperature, but, when it was found practically impossible to tabulate the formula, this last factor was changed so as to make it depend on the difference between the dry and wet temperatures. This factor is so small that no account need be taken of it except in extreme dryness and then it is necessary to consider the original formula or else errors of 40 or more degrees will occur in the dew-point.

FERREL'S CONVECTIONAL THEORY OF TORNADOES.

By William Morris Davis and Charles Emerson Curry.

(CONTINUED.)

8. *Development of Moderate Convectional Instability.*—Having now examined the physical conditions that determine atmospheric instability, from which convectional motion may arise, let us next examine the manner in which these conditions are brought about. The answer is already given in part. Figure 1 shows that summer afternoons are in this respect strongly contrasted with winter nights, or torrid with frigid regions; and figure 3 shows the importance of plentiful vapor and high temperature as a factor, as may be illustrated over the warmer oceans, and especially in the doldrums, compared with dry air of the same temperature.

The daily dust whirls of hot deserts and the daily rains of the doldrums may be taken as special illustrations of the case in hand. The dust whirls owe the instability from which they arise essentially to a local and immediate supply of sunshine: the surface air of deserts cools to a rather low mimimum at night, but warms rapidly in the morning; mirages appear, but disappear again as the warm surface air finds some point of upward escape through the overlying heavier air. Here it is the morning sunshine that warmed the sand and the lower air; the lower air therefore expanded and lifted up all the air lying upon it; and the subsequent settling down of the lifted mass drives the whirlwind upward. This is not unlike the winding and running of a clock. We apply a certain amount of muscular force, itself derived indirectly from solar energy, to raising a weight into a position where gravity can pull it down; then as gravity pulls it down a whole train of mechanism is set in motion. So with the desert whirl: solar energy lifts the overlying air by expanding the surface layer; the unlifted mass presses down and drives the surface air upward at some point of escape.

In the doldrums, the daily growth of cumulus rain-clouds is

only a little less direct process, with the further complication of the effect of condensing vapor. The high temperature and humidity of the inflowing trade wind has been gradually acquired during a long traverse over the ocean; on slowly entering the calm belt, the temperature and humidity still increase and especially the latter, by reason of the stagnation of the air; at last the slight excess of diurnal temperature and humidity over nocturnal suffices to determine convectional uprising at noon and in the afternoon, when a great part of the accumulated vapor is condensed and falls as rain. Hence the less salinity of the sea in the calm equatorial belt than under the trades on either side. It is apparent that the solar energy, slowly stored up in the vapor of the trade wind, is expended in the doldrums very rapidly and profitably in retarding the cooling of the ascending air and thus maintaining the temperature of the equatorial atmosphere as a whole at a relatively high degree; greatly to the advantage of the planetary circulation of the wind. In comparison with the desert dust-whirls, where the instability was an immediate and local product of the sunshine of a single morning, the doldrums give us an example of instability gradually produced by the accumulated sunshine of many days over a large area; the final touch that causes overturning being given when the air lies calm and hence at the surface become warmer and moister than while rolling along in the trades.

9. *Development of Stronger Instability by Cyclonic Circulation.*—It is very likely that, under favorable conditions, instability of either almost directly local origin like that of the dust-whirls, but in damp air, or of distant and gradual production like that of the doldrum clouds and rains may sometimes suffice to cause violent overturnings, such as thunderstorms and tornadoes appear to be. But before examining the conditions in which these local storms arise, and thereby determining inductively whether they are formed in either of these ways, it will be to our advantage to carry the deductive examination of the problem still further and to consider if there be any way in which still stronger instability may arise; for the association of

tornadoes with violent thunderstorms gives reason for regarding them as the product of the most violent convectional overturnings.

The cases thus far examined depend on warming the lower air; they may be likened to making a fire at the bottom of a chimney to start a draft. In contrast with this, it is clear that if the upper air were greatly cooled, instability would follow and convectional circulation might ensue. But the question here arises, how can the upper air be cooled enough to accomplish such a result? It is well known that gases are slow to change their temperature by radiation, and hence the upper air will be slow to cool itself. Whenever opportunity is given for such cooling, as for example during a long, clear winter night, the radiation from the ground is decidedly more active than from the upper air; so much so that while the temperature is much higher on the ground than in the air a mile or so aloft in the day time, it often falls to a distinctly lower degree at night; hence the inversion of temperature so characteristic of winter anticyclones. The only effective method of producing instability by cooling aloft is, we believe, by importation of cold air from a cold region, thus superposing it on a mass of warmer air. In order to produce instability in this way, it is by no means neccessary that the upper current should be so cold as to be absolutely heavier than the lower air; but simply cold enough to be potentially heavier, that is, heavier after the pressures upon them are equalized. If, then, it be possible for two currents of air to cross each other, the lower one coming from a region where it has been warmed and moistened by many days of strong sunshine, and the upper from a region where it has been cooled by a corresponding time of effective radiation, an extraordinary instability might result in the region of their contact; an instability not due simply to the local superheating of a thin layer of surface air, as in desert dust-whirls; not due to the gradual heating and moistening of a thick layer of lower air alone; but due to the contrast between two thick layers of air of contrasted origins and conditions.

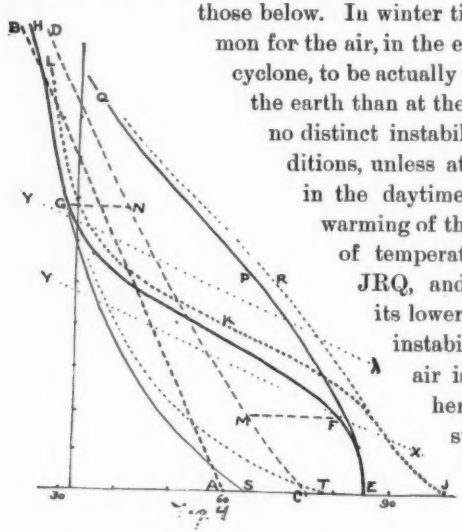
We can go still further and try to discover where the exces-

sive instability here described may be produced; for although this was not done very fully in the actual development of the theory, the essential of it was recognized deductively by Ferrel, who wrote in 1880 as follows: "As the upper part of this (westerly wind) is carried eastward faster than the lower, it overlaps the more central warmer part of the air below before it has time to cool down by radiation, and thus there is produced a more rapid diminution of temperature with increase of altitude, and a state of unstable equilibrium in which these gyrations of the air readily originate."*

It is well known that the cyclonic storms, to which our weather changes are due, draw their indrafts from regions of unlike meteorological conditions; their sirocco-like warm southerly winds coming from the Gulf of Mexico and the Gulf Stream, laden with moisture, and often further heated for a time in crossing the Gulf States; their cold or cool waves coming from the far northwest, where the air is dry and is reduced to a low temperature by effective radiation. If we follow the course of these winds, in the light of what is now known of cyclonic circulation, it is apparent that as we ascend from the earth's surface, the indraft is drawn from a more and more right-handed source. In the northern part of a storm, the northerly winds would be overrun from a point more to the east; in the southern part, the southerly winds would be overrun by others that were drawn from a more western source. It may be seen from this that there is a certain part of the cyclonic system in which the normal circulation of the storm winds will develop an instability of the kind that has seemed most effective in producing strong overturnings, such as we believe thunder-storms and tornadoes to be. This will not occur in all parts of a cyclone or in all cyclones, but only where and when the contrasted indrafts overlap in such a way that the colder is above the warmer. The southeastern quadrant contains the warmest winds and these have the highest temperature and dew-point in spring and summer; above these, the winds must be drawn from a more western and hence a cooler and drier source; and in this superposition

*Meteorol. Researches, ii, 93.

we have the cause of strong instability. All this is illustrated in figure 4. Let AB represent the mean annual vertical decrease of temperature in the central Mississippi valley; in late spring this has become CD. During the prevalence of a steady southerly wind on the east side of a cyclonic storm, CD becomes EPQ, the change from one to the other being greatest at a certain height above the ground, where the winds blow faster and come from a more distant and hence warmer source than those below. In winter time, it is not uncommon for the air, in the eastern quadrant of a cyclone, to be actually warmer a mile above the earth than at the surface.* There is no distinct instability under such conditions, unless at a great altitude, or in the daytime, when the general warming of the air shifts the curve of temperature from EPQ to JRQ, and somewhat flattens its lower part; even then the instability of the lower air air is not excessive, and hence the comparative steadiness of the surface southerly wind. A day or two later, when the storm center has moved eastward, and a northwesterly wind prevails, the temperature curve will change to SGH; the lower air is distinctly unstable now, as the cool wind moves over warm moist ground, and particularly so in the strong noon sunshine of such a time, when the curve becomes TGH. Then it is that the wind springs up in the morning, and grows to a moderate gale by noon, with many flows and slatches marking its convectional overturning; fast moving cumuli grow in size till they form shower clouds with out-spreading tops in the afternoon, but their rain is short lived, for they have but small



* For examples on Mt. Washington, see Science VII, 40.

supply of warm and moist air to draw upon. A day later, when the ground is colder and drier, the clouds are fewer and smaller, and showers seldom occur.

It is the transition from one of these conditions to the other that interests us. When the storm center lies to the northwest and the southerly winds still prevail at the surface, the westerly winds will have arrived aloft, bringing a low temperature, and thus twisting the curve from EPQ to EFGH, and in the daytime to JKL; and this is manifestly a condition of extraordinary instability. The lower air is moist, and MF or more degrees warmer than the normal for the season; the upper air is dry and nearly GN degrees cooler than the normal. The locus of maximum instability as at altitude K, where JKL is flattest; not at the ground, as it will be a day later: and an upsetting once started will be long maintained by a vast supply of very warm, damp air. This is surely an extreme of instability. It may be noted that, although the upper air is colder than the lower air, it is not necessarily enough colder to be absolutely heavier, in spite of the less pressure upon it. Reye has shown that this occurs only with the excessively rapid vertical cooling of 5.4 degrees in 300 feet of ascent, a rate that is represented by the lines XY. Such a difference between the temperatures of the southerly and northwesterly winds probably occurs in winter, with the advent of a cold wave; and then there is reason to think that the cold air pushes its way along beneath the warm, the line of meeting and mixture being marked by snow squalls and followed by a blizzard.

Thus far, the discussion has been intentionally deductive, as the latter part of the second step of an investigation properly should be: but we believe it to be in accord with correct physical principles, and we have attempted to check it at several points by means of well known meteorological phenomena. Finally, we have deduced what seems to be the condition of things best adapted for the development of tornadoes, and here we find excellent opportunity to test our hypothesis and its ultimate deduction by bringing it face to face with facts. To this we may now proceed.

10. *Tornadoes Occur in Regions of Cyclonic Instability.*—Let us now inquire if the observed location of thunder-storms, tornadoes and waterspouts give countenance to our hypothesis. If no relation exists between cyclones and tornadoes, we should be persuaded that something is wrong in our suggestion or deduction: but if the predicted relation is found to obtain, we should be encouraged to think we are on the right line of explanation, and we may go on with better confidence to the remainder of the study. In this inquiry, we may follow something of the historic order.

In the first place, the occurrence of tornadoes chiefly in warm weather and at warm hours indicates their dependence on sunshine for their opportunity; and from the time of Franklin's recognizing this, it has been the prevailing theory. But that direct sunshine is not their only control is also apparent from the fact that they do not occur on every hot day and only in the day time. In Ferrel's earlier papers, he implied when stating that tornadoes occurred in calm air and that waterspouts were unknown in winter,* that the essential element in their production was an immediate supply of strong sunshine; but his latter essays recognize the more newly discovered facts in the case, and the necessity of some additional control to explain their time and place of formation; these slight lapses in his early essays being like a few others that are referable to the highly deductive character of his studies, which they illustrate so well that we can hardly regret their occurrence. It is true that tornadoes and thunder-storms often occur in sultry days of light wind, and it cannot be at present denied that they may arise in a calm atmosphere; but the fact of their general occurrence in cyclonic areas, as stated below, indicates that the greater number of them are not due to instability of local origin alone.

On the other hand, Hazen objects to the efficacy of sunshine* in the production of tornadoes because the stronger effect of the sun's heat extends to but a moderate height above the

* Amer. Journ Science xxxi, 1861. 42.

* Amer. Journ. Science, xxvii. 182; Amer. Met. Journ. iv, 171.

ground, and because any movement in the thin layer of air thus warmed would be too much impeded by friction with the ground to attain great violence. But this seems to us illogical in not recognizing the diurnal effect of the sun's heat for what it is worth, and in failing to infer from the hour and season of most frequent tornadoes that direct sunshine has a strong hand in their production.

The preparation of daily weather maps some years ago brought to light what appears to be the most important factor in the generation of tornadoes and other local storms. In 1867, Fron announced* that thunder-storms and tornadoes in France were definitely related to the larger cyclonic storms, occurring only in their dangerous semi-circle; but the fact was not discovered in our country till some years later; so many years later indeed that discussion as to priority of discovery seems rather out of place. Professor Abbe has told us that the occurrence of local storms chiefly in the southeastern part of cyclonic storms was noticed and made use of early in the history of the Signal Service in this country—consequently some fifteen or more years ago. Later on, excellent and most distinct indication of this most important fact was given in the special weather maps prepared by Lieut. Finley to illustrate the remarkable series of tornadoes in the Southern States on Feb. 19, 1884. Finley had previously† come to the conclusion that tornadoes were located in a zone of contrasted temperature; a zone between the warmer southerly and cooler northerly winds that are drawn together by a cyclone; but it appears now that the line of meeting of the southerly and westerly winds is not always distinct at the time of tornado occurrence, that the horizontal contrasts of temperature on this line are likewise often not notably strong, and that the chief locus of tornado occurrence is one or two hundred miles eastward of the line. Something of this was shown by Finley in a later publication.‡ Hazen has also discussed the question,§ but is thereby led to

* Ann. Soc. Met France, xv, 1867, 137, 152.
† Prof. Paper 4, U. S Signal Service, 1881, 109,
‡ Prof. Paper VII, 1882, 17.
§ Amer. Met. Jour. i, 1884, 121-127.

conclude that contrasts of temperature do not enter the problem. He gives 453 miles as the average distance of tornadoes from the cyclonic center that they accompany. Thunder-storms are also known to be similarly located.

An article* by the senior author of this essay presented a similar conclusion as to the locus of tornado generation, illustrating it by means of "composite portraiture," and suggesting that the instability to which the tornadoes were due was not lateral but vertical; that the cool westerly winds rose when they reached the warmer southerlies and flowed over them. Hazen took exception to this, maintaining that the colder current would underrun the warmer, not overrun it,† and his objection appears well taken. Köppen also criticised the idea adversely, but added what seems to the true explanation of the matter, namely that, the southerly winds are overrun by the upper westerly current, not by the rising of the surface current; and this brings us to the point already reached by Ferrel's deduction and by the explanation given above. The normal cyclonic circulation brings winds of unlike temperature and humidity into superposition; and in the southeastern quadrant, this is such as to cause instability, even to the point of developing tornadoes.

The reader must judge for himself how far this may be accepted as verification of the convectional theory of tornado generation. The reality of the superposition of the contrasted winds in such manner as to bring about the conditions of figure 4, is evidently the main point in the problem. If the cyclonic winds ran in true circles around the center of low pressure, or if their inclination to the storm radius were constant at all altitudes,‡ no superposition of the kind in question would be possible; but such is not the case. The more right-handed origin of the wind aloft has received increasing confirmation since it was first noticed in Redfield's time. Numerous observers have independently and by purely inductive methods come to this conclusion. The theory of cyclonic action, as developed by Fer-

* Amer. Met. Journ., I, 1884, 121–127.
† Amer. Met. Journ. I, 1884, 173
‡ Compare Hazen, Amer. Met. Journ , I, 174.

rel and by Guldberg and Mohn, leads to the same result. Indeed, anyone who will watch the formation of thunder clouds in the summer time must come to the same opinion. They characteristically appear during the presence of a light southerly warm or hot wind; their massive clouds are overtopped, as they rise in the west, with a far eastward-reaching cirro-stratus sheet, while on the rear of the storm the same sheet extends but little way westward. In Wisconsin, I am informed by President Chamberlin, of the State University, that these cirro-stratus sheets are so common that, as a boy, he and his fellows called them "threshing-machine clouds" from their peculiar overreaching form. This can only be explained by accepting the existence of a westerly current aloft above the southerly surface wind. The progressive motion of thunder-storms and tornadoes leads us to the same end. These storms have certain internal motions of their own, but they seem little more capable of self-progression than ordinary clouds; they float along in the current in which they are formed; and inasmuch as they generally move from the southwest or west, even though occurring within the area of southerly surface winds, it is reasonable to conclude that they are controlled by the course of the great mass of air through which their convectional currents rise. If the existence of the overlying westerly current be accepted, its relatively low temperature and humidity follow as necessary corollaries to the main proposition; and from these follow again the instability of the whole mass.

The only objection that we have encountered to the above statement concerning the fact of the location of tornadoes in the southeastern quadrant of cyclones is by Llewellyn,* who maintains that inasmuch as tornadoes are found sometimes on the northwest side of cyclonic centers, it is a mistake to say that there is any "law" governing the distribution. This is rather a play on the word, "law," than a successful attack on the ordinary form of the statement concerned; for Llewellyn's own tables show that thirty-three of the forty-nine tornadoes that he had looked up occurred to the southeast or south of a

* Amer. Met. Journ., v, 83.

cyclonic center. Other causes than cyclonic circulation undoubtedly have a hand in determining the time and place of tornado occurrence, but none seem of so great an importance as this.

11. *Finley's Report on the Tornadoes of 1884.*—Before going further in our general discussion of the tornado problem, it will be advisable to insert the result of a recent careful examination of Finley's report on the tornadoes of 1884.* As no extended review of this valuable paper has yet appeared, we are disposed to consider it here at some length. It presents in tabular and graphic form the results of Finley's collection of tornado records from numerous volunteer reports in all parts of the country for the year concerned, and is undoubtedly the most valuable and extended collection of specific facts yet published on this subject. In view of this, it was with much regret that we found, on examining it closely, many traces of unskillful editing, by which its value is much reduced. Its most serious blemish is the lack of accord in its several parts. For example, on April 1st, seven tornadoes are given in the tabular list of tornadoes for the year; the first and sixth of these are correctly plotted on the maps of the corresponding date; the second and fourth are not plotted at all; the fifth and seventh are out of place from eighty to a hundred miles; and the third is plotted as running E. N. E., while the table gives its course E. 10° S. Moreover, there are three tornadoes in Ohio, three in Indiana, one in South Carolina and one in Mississippi, or eight in all, that appear on the maps of this date but of which no mention whatever is made in the table; and finally, the fourth one in the tabular list is not on the general chart of tornado distribution for the year. Again, on April 14th, there are five tornadoes given in the table, two of which are not on the map; and there are twelve on the map in various states not in the table. This disagreement has greatly increased the labor of using the report. Further difficulty arises from the use of "local time" in the text accompanying the maps; for this has to be reduced to eastern time in order to place the tor-

* Tornado Studies for 1884. Prof. Paper xvi, U. S. Signal Service, 1885.

nadoes referred to in their proper attitude with respect to the neighboring cyclonic center, and this reduction should have been made at once for all before publication. The lack of any simple means of identifying the tornadoes on the map and in the table is another obstacle to convenient work; and the utter confusion in the arrangement of stations in the weather tables accompanying the maps makes it a tiresome undertaking to discover local records. We also found, in looking over the text accompanying the maps, that it was exasperating to encounter on every page the trite homily, "A careful study of this table in connection with the chart will prove of interest;" such a recommendation might have been expressed once for all in a preface. We make no complaint concerning the manifest imperfections of the data in the report; for it is understood that reports from volunteers must be uneven and irregular; we are under great obligations to them for the pains they have taken; nor can we infer indifference or neglect from so industrious a worker as the author of the monograph is known to be; the collection of data from which the volume is compiled is due to his energy and perseverance; but we believe the scientific public is entitled to greater care and skill in the preparation of government reports than are exhibited in this one.

In spite, however, of all these faults, it may still be said that Finley's report on the tornadoes of 1884 contains the most serviceable collection of facts in the matter of the relation of tornadoes to cyclones that has yet appeared. A careful examination of its maps and tables has led to the construction of figure 5, in which all the tornadoes that could be identified are placed in their proper positions with respect to the center of the cyclone that they accompanied. The dots show the position of those whose track was not defined; the little arrows indicate the position and course of such as were more fully observed. While it is apparent that a considerable number of tornadoes are aberrant, it is equally clear that the greater number of them occur within tolerably well marked limits, namely, within the southeastern octant of the cyclone and from three to eight hundred miles from its center of low pressure; and it is noteworthy

that practically none occur to the north of the cyclonic center. The preponderance of tracks from southwest to northeast is perfectly distinct; but several other courses are indicated. By reference to the original maps, it may be seen that the tornadoes as a rule appeared decidedly to the east of the line of most rapid change of temperature, as has been mentioned above. In view of all these results, it may be accepted that tornadoes have a definite relation to the larger atmospheric disturbances within which they occur; and it is reasonable to infer that the origin of the smaller storms depends on conditions brought about by the larger ones.

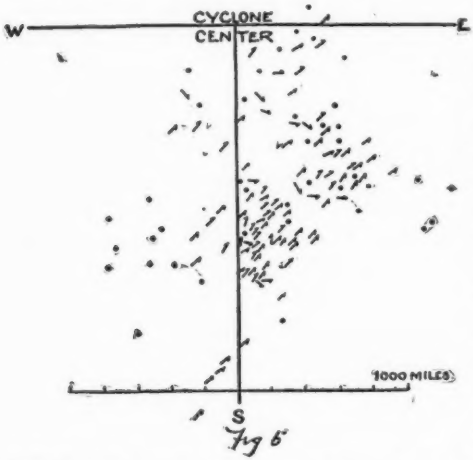


Fig 6

12. *Geographic Control of the Occurrence of Tornadoes.*—The high temperature and humidity and the contrasts of temperature requisite for the production of tornadoes are not developed by every cyclone or in every part of the world. Most cyclones give only general rains, without even thunder-storms; in others, thunder-storms occur of considerable intensity, but tornadoes are still absent; the cyclones that are accompanied by tornadoes seem to be exceptional in time and place. Seasonal and diurnal conditions that assist in the production of high temperature and humidity are probably among the most important elements in addition to the cyclonic circulation; and in lead are so important that they seem sometimes to be capable of generating tornadoes alone, as has already been indicated. Geographic conditions are certainly also of much value in determining contrasts

of temperature and moisture in the cyclonic winds, as will appear shortly. And besides these, there seems to be something, not yet fully understood, in the quality or quantity of the cyclonic circulation that exercises a considerable control over the occurrence of local storms; whether this is form of isobars, velocity, direction or volume of wind, cloudiness or other feature of the cyclone is still to be determined.

It remains to consider why tornadoes should frequent the central and southeastern part of the United States,* rather than to the plains to the west or the ocean to the east. This fact of distribution seems to depend on the outline and form of the country, by which warm and moist southerly winds meet here with cool and dry westerly winds in sharpest contrast. The Gulf of Mexico and the Gulf Stream in the Atlantic supply plentiful moisture at a rather high temperature, and the temperature rises still higher as the winds advance in the daytime over the southern states. On the other hand, the open country of the northwest is dry and cool; and no mountain barrier between these two sources obstructs the contact of their winds. But on the western plains, the southerly winds are too dry to promote the strongest instability: north of the lakes, there are no westerly winds till the southerlies are carried far eastward by the advance of the storm center; on the Atlantic slope, the cool westerlies have advanced so far from their source as to have lost much of those peculiarities on which instability depends; and the same may be said of the ocean: though in winter time, when the land is cold and the water relatively warm, waterspouts often occur during westerly off-shore winds.† In Europe, westerly winds are not so cool and dry as with us and tornadoes there are exceptional. Indeed, nowhere else in the world is there the same geographic opportunity for the production of tornadoes as in the Mississippi basin, where observation shows them to be more frequent than in any other country: but this is a pre-eminence in which we can have little gratification.

(TO BE CONCLUDED.)

*See chart of tornado frequency by Finley, Prof. Paper VII, U S. Signal Service, 1882.

†Gibson, Waterspouts on the Gulf Stream in Winter, Amer. Met. Journ., iii, 119-127.

CORRESPONDENCE.

SCALE FOR ANEMOMETRIC SHEETS.

To the Editors:—To any one who has attempted accurate measurements of wind velocities—maximum, extreme, and current—from the style of anemometer now in use by the Signal Service, the need of a scale divided off into minutes and fractions of a minute, so that the calculation of these velocities are absolutely correct, has presented itself. About six months ago the writer endeavored to have made such a scale and after trying various makers of scientific instruments succeeded in having manufactured what is now known as "Carpenter's Anemometer Scale," an instrument in the shape of a flat ivory rule, divided into five minute spaces, for getting out the maximum or current wind velocities; and with these divisions subdivided on one side into whole minutes and on the other into half minutes, all calculations relative to wind velocities are assured. Such a scale has been in use at this Signal station for a period covering six months, and no errors in the wind-form have been detected by those examiners of all examiners, the office of the Chief Signal Officer, Washington City.

It seems strange that such a device has not been thought of before, as its simplicity commends itself to all meteorologists.

Ford A. Carpenter, Signal Corps.

Portland, Oregon, November 20, 1889.

THERMOMETER ERRORS.

To the Editors:—In connection with Prof. Rogers' letter in the December Journal, relative to "Thermometer Errors," I would like to give briefly the results of a few experiments I made in September last. I had been so fortunate, earlier in the summer, as to hear from Prof. Rogers himself, more or less of the details of his studies in thermometer comparisons, and was greatly interested in looking over his results which show a clearly marked periodic variation of the difference between two thermometers subjected to exactly the same temperature and

whose difference, within small limits of temperature changes, should, therefore, remain constant.

The observed facts, moreover, fitted very nicely into a mathematical theory developed by Mr. Woodward. The matter was of great importance to me, as some doubt was thrown upon the accuracy of the results obtained in the comparison with standards of the large number of thermometers used by the Signal Service, and I desired very much to assure myself that noticeable errors did not systematically occur in our comparisons. In observing thermometers after the manner followed by Prof. Rogers, where the readings are made by telescope, I was soon convinced that accurate estimations of the fractions of degrees could only be made with difficulty, and if the light was a little bad, a matter very troublesome to control, the estimations were particularly inaccurate when the end of the mercurial column was near a graduation line.

In order, therefore, to remove all doubt whatever, as to errors of estimation, I substituted for the ordinary telescope one provided with a micrometer eye-piece. The apparatus enabled me to subdivide a degree on the thermometers into about 200 parts, and the limit of error of quite an indifferent setting of the micrometer did not exceed $1\frac{1}{2}$ hundredths of a degree.

The exposure of the thermometers is, as one might imagine, of very great importance, and for great accuracy I am inclined to think the thermometers must be immersed in water or similar liquid kept well stirred and thoroughly mixed. In the experiments now under consideration a water bath holding from two to three gallons of water was used. The temperature was made to slowly change as desired by causing a small stream of water at a different temperature to flow into the bath, which was provided with a suitable overflow. Observations were made regularly once a minute and the bath stirred between times.

The result of several series of observations of from one-half to two hours duration give no evidence of a periodic variation in the differences between the thermometers. The small errors of observation, when the results are plotted on a large scale, appear in the irregular character of the line of temperature,

but the line as a whole is noticeably straight. It appears therefore, I think, that thermometers in stirred water take up temperature changes in a perfectly regular manner and the tendency to produce pulsations is either so small as to be inappreciable or is quite effectually eliminated. I have not had the time to study the effects when the thermometers are exposed undisturbed in the air, but I am inclined to think now that the pulsations provided for in Woodward's theory are, in ordinary thermometers, of rather short period and of very small amplitude, probably quite inappreciable. I intend when I have the opportunity to try a thermometer of special construction having an unusually thin walled bulb and a stem of fine bore.

Coming more directly to the special phenomenon cited by Prof. Rogers, that of the seeming halt of the column behind the graduation marks, I have noticed it myself but am almost sure it is not real. The confusion, even in a first-class telescope, of the end of the column of mercury with the graduation line, and the consequent inaccurate estimation of the position of the end of the column, are sufficient, I think, to explain the matter. In the use of the micrometer the thermometer is turned so that the graduation lines appear to one side of the column. The graduations merely serve to evaluate the divisions of the micrometer and furnish a reference mark by which to preserve a fixed relation between the telescope and the thermometer.

C. F. MARVIN.

WASHINGTON, D. C., Dec. 13.

CURRENT NOTES.

FORECASTS FOR FORTY-EIGHT HOURS IN ADVANCE.—Appreciating the great importance that long-time predictions possess for the general public the Chief Signal Officer authorized forecasts for forty-eight hours, covering the second day, in advance. Such predictions were optional with the predicting officer and were only made when clearly in the public interest and covered in all cases, considerable areas of country, and were not confined to localities.

Percentage of verifications of forecasts made for second day in advance:—number of predictions made; weather 19, temperature 41. Percentages of verifications; weather 67.1; temperature 71.5. Weather and temperature combined, 68.9.—*Monthly Weather Review for July.*

Monthly Weather Review.—We rarely refer to the *Review*, in part because it is so full of matter interesting to meteorologists that we do not know where to begin with it, and in part because it reaches a large portion of our readers. It has developed from the few octavo pages of ten years ago to the 32 quarto pages of the present, with its pages and charts crammed with condensed facts and figures concerning the weather of the month. Some improvements in treatment lead us to refer to the number for last July which is edited by Lieut. Finley,—whose name we do not remember to have seen on the title page before for several years. The most notable change is in the treatment of cyclonic and anticyclonic areas, where the facts for the month are first generalized and compared with previous years before the list of anticyclones and cyclones is given. Heretofore such information was given only, or mostly, under the individual storms. The innovation increases the interest and usefulness of this part of the *Review* without expanding the space occupied by it.

Hutchins and Owens' Recent Study of Lunar Radiations.—Hutchins and Owens have experimented on the thermal radiations from the moon; their paper is published in the Proceedings of the *American Academy of Arts and Sciences*. The instrument employed by them was a single thin thermo-electric couple with a galvanometer. The radiation from various rocks at a temperature of 100° C. was surprisingly uniform. In observing the moon considerable variations were found, even on evenings apparently cloudless; these are attributed to invisible clouds. The heat of the moon is absorbed by quartz much as is the heat from an incondescent platinum coil. The radiation of the sun was found to be 184,560 times that of the moon; this

is only about half as much heat as is usually attributed to the moon. During an eclipse the heat from the moon almost entirely disappears, showing that the radiations from the heated lunar rocks is probably mostly stopped by our atmosphere. At the same time, they found that the atmosphere, at average pressures, would transmit 89.25 per cent. of a vertical lunar beam.

DR. HINRICHS in a recent circular to his observers says:

It is now fourteen years since I established the first State Weather Service in the United States. It is ten years since I built a special Meteorological Observatory, the only one in this country at which observations are taken and published in accordance with the rules of the International Congress of Meteorology of Vienna and Rome.

Three volumes of Reports were published before any State aid was given; eleven have been published since. The work has never stopped—and neither myself nor our Volunteer Observers of Iowa will allow it to be interrupted.

Having accepted the call to the chair of chemistry in a professional college at St. Louis, I shall in a few weeks enter upon my new duties, the more liberal earnings of which enable me to say that my Meteorological Observatory at Iowa City, and my State Weather Work here ih Iowa, are now beyond the reach of those who have persecuted me in Iowa as no scientific investigator ever was persecuted in free America.

My legal residence will remain at Iowa City, Iowa. My office will remain here, as it has been for twenty-seven years. My clerk will attend to all current matters, and transmit to me, unopened, all letters marked "personal" or "confidential."

During the five winter months I expect to come up to Iowa City at the close of each month to make up and publish the monthly bulletin.

During the summer season I expect to live at my residence and observatory at Iowa City, and to spend a large portion of my time on the meteorological work which I have carried on for so many years, and in which I have had and expect to retain the assistance of liberal and enlightened friends throughout the State.

In this connection we may be permitted to copy the following words on his work done for the University, from page 25 of the Report of the Legislative Investigating Committee:

"Professor Hinrichs has given to the University the best years of his life, and has probably contributed more than any one man to its upbuilding. His recognized ability and eminence in his profession has been a tower of strength to the scientific department of the institution."

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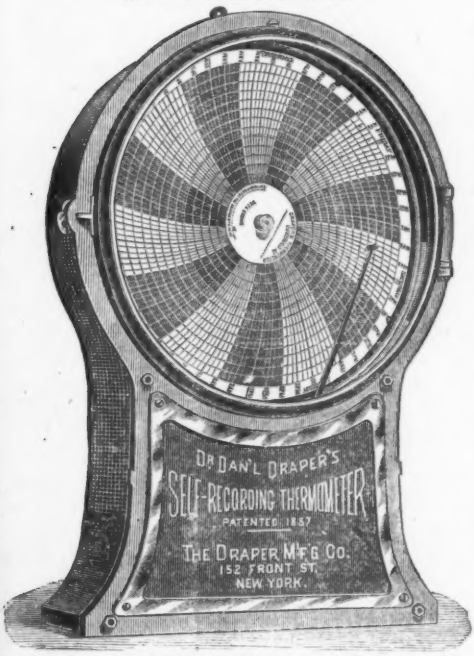

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